Considerations for the Smoky Canyon cover system

Currently there are four cover profiles under consideration for the Smoky Canyon Superfund site. They have been carefully modeled and tested in lysimeters on site. The work that has gone into those tests and models is extensive. They show that an alternative cover can work on this site and the only debate is exactly which cover design would be best for the site- for the hydrology, ecology, economy, and regulatory acceptance.

The covers suggested, with diversion layers, impermeable layers, and capillary breaks, work well on paper or perform well in test plots but are prone to failure in actual field installations. Roots intrude, fine grain materials fill in among larger grain materials, carefully placed layers shift with freeze thaw cycles, and planted grasses yield to trees and shrubs – as Craig Benson said, "Ultimately nature is going to make the mine cover similar to the surroundings."

I think that the answer is yes to an evapotranspiration (ET) cover, but no to those exact cover designs. None of the covers proposed takes into account the ecology of the area. Mixed coniferous forest is the dominant ecosystem for the area.
http://ecologicalregions.info/data/id/id_front.pdf

Each of the suggested cover systems use grass as the vegetation layer, which is not long term viable for the site. The site will inevitably transition from grass land to shrub and tree – it should be planted from the beginning with trees that form the natural ecosystem for the area.

Planting a coniferous forest instead of grass makes a superior ET cover for three reasons: increased precipitation interception, extended season transpiration, and the addition of understory transpiration and water consumption. A cover that incorporates a natural forest ecosystem will work to prevent rain and snow from percolating into waste, be simpler, more resilient, use fewer resources, will grow better and become more efficient every year. In addition, a forest cover will create wildlife habitat and sequester carbon. In the pages below I highlight some research into those areas and explain how they impact the cover selection for the Smoky Canyon site.

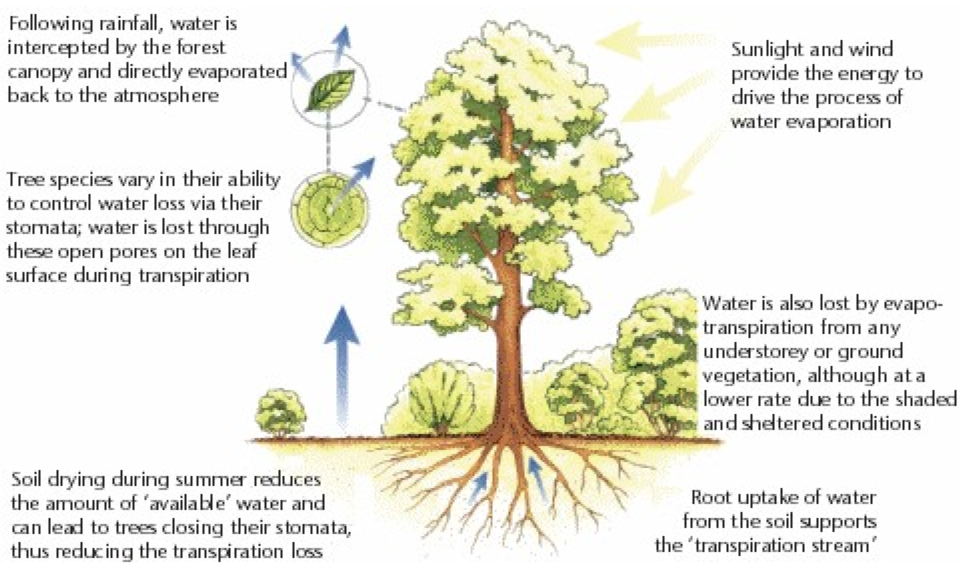
Interception: Most cover models, including those used in the Smoky Canyon designs, use potential evapotranspiration as a value derived from weather data. These models do not understand that different plant ecosystems have different ET values. In a conifer forest a large percentage of precipitation is intercepted by the vegetation; it never reaches the ground.

There are numerous studies that measure high percentages of interception in coniferous forests, including one long running watershed size study in England:

https://www.forestresearch.gov.uk/research/forest-hydrology/forest-hydrology-how-much-water-do-forests-use/

Coalburn, in Britain is the home of a 35 year forest hydrology research catchment study, providing a unique record of the long-term effects of conifer afforestation on water supplies.

They found that “Trees and forests have the ability to use more water than shorter types of vegetation. In general, conifers catch between 25 to 45% of annual rainfall by interception, compared to 10 to 25% for broadleaves and almost 0% for grass.”



How trees use water Forestry Commission Information Note 65: Water use by trees.

Studies published by the UN (Forests, Climate, and Hydrology: Regional Impacts (UNU, 1988, 217 pages) also show that coniferous forests intercept about 20-25% of precipitation:

TABLE 1. Ratio of precipitation reaching the soil surface to precipitation amount falling on forest**.**

Forest type	**Average forest density**	**Portions of precipitation reaching the surface**		
		Oct.-Apr.	**May-Sept.**	**Year**
Spruce	0.8	0.75	0.75	0.75
	0.4	0.80	0.80	0.80
Pine	0.8	0.80	0.80	0.80
	0.4	0.90	0.90	0.90
Pine-spruce	0.8	0.75	0.75	0.75
	0.4	0.85	0.85	0.85
Mixed	0.8	0.92	0.80	0.85
	0.4	0.97	0.85	0.90
Deciduous	0.8	1.00	0.85	0.90

	0.4	1.00	0.90	0.93
Deciduous brushwood with coniferous undergrowth	1.0	0.95	0.80	0.85

Krestovsky 1969a; Krestovsky and Sokolova 1980

Monthly precip average for the Smoky Canyon varies between 1.5 to 2.5 inches. Decreasing that by 25% or more due to canopy interception would decrease the size of the soil sponge needed for an ET cover and the eliminate the need for interception and diversion layers.

2018 Annual Report Pole Canyon NTCRAs
Performance and Effectiveness Monitoring
Smoky Canyon Mine

July 2019

Table 3-1
Monthly Precipitation Totals for the Smoky Canyon Mine (2004–2018)

Month	Monthly Precipitation (inches)															
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	15-Year Average (2004-2018)
December[1]	2.81	1.64	4.31	1.94	2.18	2.02	1.52	2.73	0.97	2.74	1.83	1.77	1.39	3.31	1.63	2.19
January	2.27	2.08	4.18	0.85	2.72	2.85	1.99	2.61	2.24	1.63	2.11	1.01	3.33	4.89	2.09	2.46
February	1.35	1.40	1.41	1.50	1.86	1.99	0.97	1.73	2.25	0.99	4.72	0.96	1.54	5.5	2.08	2.02
March	1.17	2.16	2.07	1.19	2.38	2.56	0.86	3.32	1.10	1.84	2.34	0.79	2.56	2.46	2.80	1.97
April	1.52	1.38	2.37	1.89	1.31	2.54	3.36	4.24	2.22	2.47	1.57	1.74	2.00	3.09	2.58	2.29
May	4.19	4.13	1.02	0.47	2.60	2.56	1.91	3.14	1.77	2.61	0.93	5.40	3.64	1.89	2.21	2.56
June	4.39	3.24	0.91	0.77	2.33	6.31	2.89	2.09	0.11	0.09	1.60	1.38	1.01	1.12	1.39	1.98
July	0.78	0.52	0.90	1.51	0.02	0.57	0.26	1.92	0.96	2.00	0.63	1.63	0.27	0.15	0.24	0.82
August	2.63	1.52	1.22	1.09	0.67	1.11	1.78	2.20	0.04	1.12	5.06	1.45	0.64	1.36	1.27	1.54
September	2.89	1.31	2.14	1.50	1.69	0.29	0.50	0.36	0.42	2.92	4.34	2.68	4.82	3.13	0.18	1.94
October	3.74	1.39	1.67	3.00	0.66	2.25	2.79	2.66	1.67	1.84	0.91	0.53	5.79	0.75	2.43	2.14
November	0.72	2.58	3.02	1.03	2.66	0.21	2.79	1.85	1.92	1.34	2.86	2.25	1.12	2.97	1.67	1.93
Total	28.46	23.35	25.22	16.74	21.08	25.26	21.62	28.85	15.67	21.59	28.90	21.59	28.11	30.62	20.57	*24.08*

Understory and decomposing plant layer: The ET part of a forest is three dimensional including the tree canopy, the plants that grow beneath the canopy, and decomposing plant-animal biome on the forest floor.

A recent article compared natural soils in various forests for their water holding capacity:

Comparing the Water-holding Characteristics of Broadleaved, Coniferous, and Mixed Forest Litter Layers in a Karst Region1 August 2018

Qiuwen Zhou, David M. Keith, Xu Zhou, Mingyong Cai, Xingfen Cui, Xiaocha Wei, Yaxue Luo

https://bioone.org/journals/mountain-research-and-development/volume-38/issue-3/MRD-JOURNAL-D-17-00002.1/Comparing-the-Water-holding-Characteristics-of-Broadleaved-Coniferous-and-Mixed/10.1659/MRD-JOURNAL-D-17-00002.1.full

Abstract

Karst forests are often located in mountainous regions, and because of various geological factors both soil and water loss are major conservation concerns. We investigated the water-holding characteristics of 3 typical karst forest types through field sampling and laboratory experiments. The results showed that (1) the total litter mass of the coniferous forest was significantly higher than that of either the mixed forest or the broadleaved forest; (2) the mass of semidecomposed litter was significantly higher than that of undecomposed litter; (3) the litter layers of the mixed and coniferous forests had similar maximum water-holding capacity, whereas the maximum water-holding capacity of the broadleaved forest was significantly lower; (4) the maximum water-retention capacity of both the mixed and coniferous forests was significantly higher than that of the broadleaved forest; and (5) water-absorption rate and maximum water-holding capacity varied significantly across forest and litter types, with the mixed forest and undecomposed litter layers tending both to hold more water and to absorb water more quickly than the other forest types or the semidecomposed litter layer. Because of the elevated water-holding capacity and absorption rate of the mixed forest in karst regions, special emphasis on the conservation of this complex forest ecosystem is critical from both hydrological and ecological perspectives.

An article that suggests that modeling needs to take into account biological as well as meteorological data:

Modeling water uptake on coniferous forest Oregon watershed 10: synthesis

Waring, R. H.; Running, S. W.; Holbo, H. R.; Kline, J. R. 1973. Modeling water uptake on coniferous forest Oregon watershed 10: synthesis. Seattle: University of Washington; Coniferous For. Biome Internal Rep. 79. 20 p.

Abstract:

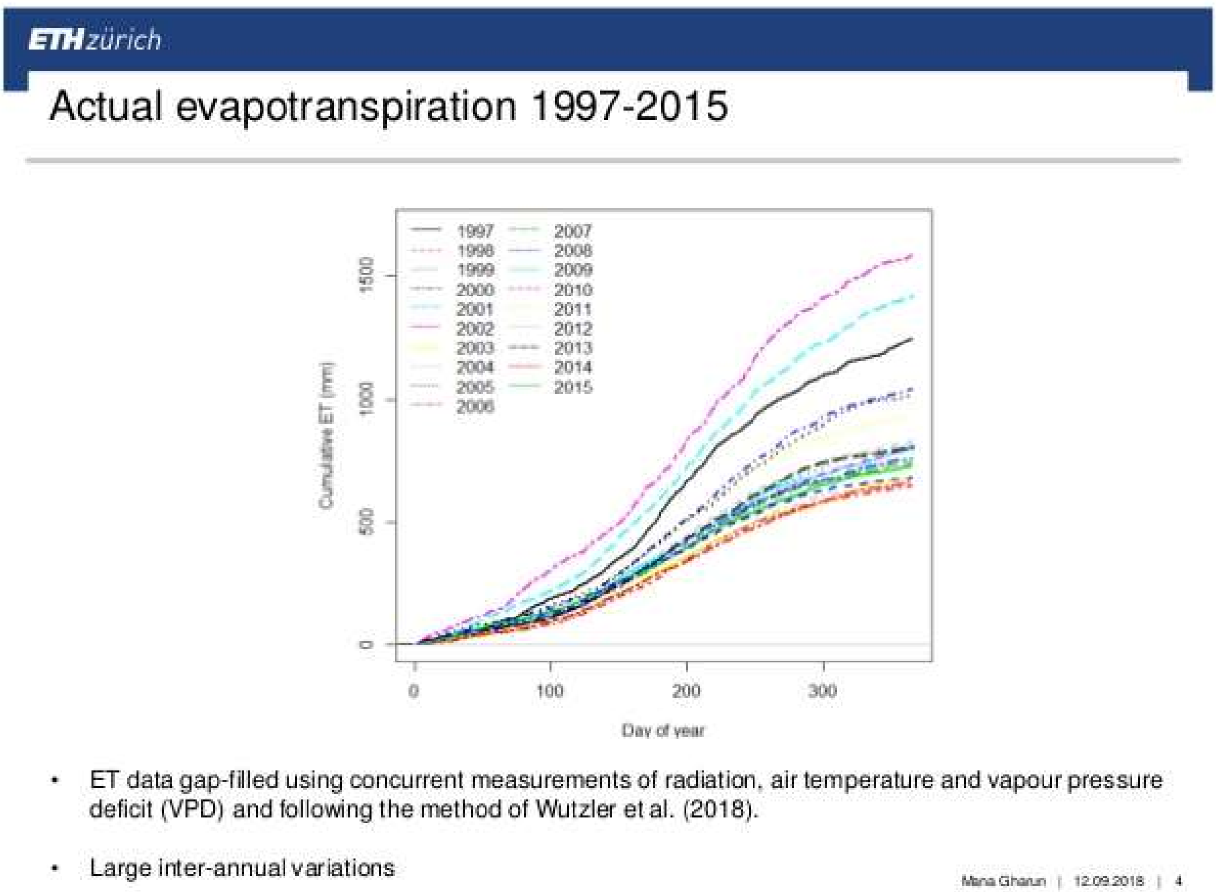
In the Coniferous Forest Biome, many of the understory as well as dominant plants are evergreen and thus water uptake is a year around process. The flow of water from the soil through plants to the atmosphere affects the entire forest ecosystem. As water is evaporated, it absorbs heat and influences the energy budget; as it is conducted through vascular plants, it carries nutrients; and as it is removed from the soil, it reduces seepage and water available to free-living soil organisms.

It is important in an ecosystem model that the hydrologic, biologic, and meteorological processes be coupled in a realistic manner. It is the objective of this report to suggest a coupling that is both practical and theoretically sound.

Nothing beats long term measurements. Years of coniferous forest measurement show ET values of 500 mm to nearly 1500 mm of ET- a great deal more than the 200 to 250 mm calculated for the covers for Smoky Canyon:

Twenty years of evapotranspiration measurements over a sub-alpine coniferous forest in Switzerland

https://www.slideshare.net/ICOS_RI/twenty-years-of-evapotranspiration-measurements-over-a-subalpine-coniferous-forest-in-switzerland/4



In the report: FIELD HYDROLOGY OF THE SIMPLE 1 AND GCLL FINAL COVER TEST SECTIONS FOR THE EAST OVERBURDEN PIT AND THE NORTH PIT BLACKFOOT BRIDGE MINE, ANNUAL REPORT FOR CALENDAR YEAR 2016, Report No. WGL-17-23 by Dr. Craig H. Benson, two cover systems are measured near the Smoky Canyon mine for several years. From the the Report, "Hydrological and meteorological data collected from the Simple 1 and GCLL test sections for the East Overburden Pit (EOP) and the GCLL test section for the North Pit (NP) at Blackfoot Bridge Mine are described in this report. Data were collected over the period 5 December 2013 to 31 December 2016 for the EOP test sections. For the NP test section, data were collected from 13 October 2016 to 31 December 2016. Monitoring systems at the EOP and NP are collecting all of the required data. The 2016 water balance from the test sections is summarized as follows:

Water Balance Quantity (mm)	EOP		NP
	Simple 1	GCLL	GCLL
Precipitation	567.2		139.2*
Runoff	1.3	1.2	59.8
Lateral Flow	143.1	279.6	1.2
Change Storage	48.3	63.1	11.7
Evapotranspiration	244.9	216.7	66.9
Percolation	128.7	0.8 – 1.4	0.0

In this study the average annual precipitation was 567 mm. Using the UK and UN study's estimates for precipitation interception of 25%-45% for a pine forest, the actual precipitation that reaches the ground would be between 425 and 311 mm. This significantly changes the water balance for a cover system.

In addition, the Zhou paper indicates that a coniferous forest removes 25% more than grass, considering extended season and understory. Therefore, the ET contribution of a forest cover is at least 305 mm, or 61 mm more the 244.9 mm of the Simple 1 grass cover. The Swiss forestry measurements indicate that ET in pine forests varies between 500 and 1500 mm per year.

Combining those two effects, interception and increased evapotranspiration, makes the pine forest cover significantly more effective than the grass cover, which the lysimeter measured at an average of 128 mm percolation. A pine forest cover can use at least 200 to 500 mm more water per year than a grass cover. A pine forest cover could prevent all percolation with a comfortable safety margin.

The soil for a pine forest ET cover should be a single deep layer that replicates the native soil closely. The forest roots are deeper and more extensive than grass roots, so in an ET cover those roots can draw deeper from the soil "sponge". A simple exploration can reveal how deep are the natural soils in nearby undisturbed pine forests. The pine forests ET cover does not need multiple layers of different kinds of soil, clay, or fabrics.